# APPENDIX B

## WORLD WEATHER PROGRAM

The Department of Commerce (DOC) was designated by the President, following Senate Concurrent Resolution 67 (1968), to be the lead agency for coordinating United States participation in the World Weather Watch Program (WWWP). Until 1983, DOC published a separate report on WWWP plans. Beginning with the 1983 edition of the *Federal Plan for Meteorological Services and Supporting Research*, a section on the WWWP has been included, obviating the need for a separate report.

## The Global Observing System: Its Impacts and Future

BGEN John J. Kelly, Jr. (USAF, Ret.)
Deputy Under Secretary, NOAA, and U.S. Permanent Representative with the WMO

**EXECUTIVE SUMMARY**

Weather and its changes have a strong influence on almost every aspect of our daily lives. Weather ultimately determines what crops we grow, how we prepare for our daily activities, if, when and how we can travel, and how we respond to on-going or impending natural disasters. Every day, across the far reaches of the globe, Members of the World Meteorological Organization (WMO) provide vital services to help their constituents cope with weather, climate and water related occurrences. The ability of Members to provide these vital services is in large part due to the information and observations provided by the WMO's World Weather Watch (WWW) that is comprised of the Global Observing System (GOS), Global Telecommunication Systems (GTS) and Global Data Processing and Forecast System (GDPFS).

The GOS is complex by its very nature and requires international cooperation at the highest levels (Figure B-1). The heart of the GOS is a surface-based subsystem that is operated mainly by the Member's National Meteorological and Hydrological Services (NMHS) and a space-based subsystem that is operated by either national or international space agencies[1]. An NMHS-operated Global Telecommunication System facilitates the transfer of GOS observations for a myriad of purposes that range in scale from nowcasting to climate and focus on a number of diverse but cross cutting areas such as tropical storms, disaster mitigation, water resources, airport terminal weather, and agriculture.

Figure B-1. The Global Observing System is complex by its very nature and requires international cooperation at the highest levels.

This article will address the importance of the WWW GOS in "taking the pulse of the planet" by providing for improved monitoring of the Earth's atmosphere, land and water bodies - essential elements to the Global Earth Observation System of Systems (GEOSS). GOS is complemented by another WMO-supported effort, the Global Ocean Observing System (GOOS). GOOS is the framework for a coordinated and sustained international observation of the ocean and provides the primary ocean contribution to GEOSS. Strong cooperation will be required between WMO and United Nations Educational, Scientific and Cultural Organization (UNESCO) Intergovernmental Oceanographic Commission (IOC) through the Joint Commission for Oceanography and Marine Meteorology (JCOMM), and the Intergovernmental IOC-WMO-

[1] The WMO Consultative Meetings on High-Level Policy on Satellite Matters provides a forum at the highest levels for dialogue between WMO and research and operational space agencies.

UNEP (U.N. Environmental Programme Committee) Committee for GOOS.

## WWW GOS HISTORY

The WWW provides the basis for NHMS' around the world to coordinate the collection of oceanic and atmospheric observations, communicate this data to each other in near-real time, develop effective tools to use the data for society's benefit, and provide archive repositories for the data.

Since the beginning of the WWW in 1963, the GOS has provided continuous and reliable global observations for use by WMO Members. Early observational requirements of the GOS were focused mainly on synoptic meteorology and directed at the rapid expansion in civil aviation. Yet, the GOS remains dynamic and the requirements imposed upon it have continued to evolve reflecting both innovations in observing systems and societal needs.

NMHS' have borne this through better designed and integrated observation systems, improved data telecommunications, and modern high-end computers to manage data flow and produce the numerically based weather and climate products. These efforts have also led to data exchange and quality control arrangements among the NHMS' to ensure accessible and accurate data regardless of its origin.

Over time, the data richness available from the GOS has provided the global observations needed to produce consistent weather forecasts out to day seven and for predicting hazardous weather events days in advance, predictions which are now used routinely by the aviation, marine, fire weather and other diverse communities. Those improvements have occurred across a diverse number of application areas in turn resulting in increasingly positive impacts on products and services provided by NMHS' world-wide.

The evolution of the GOS was made possible by the advances in technology that have affected almost every aspect of day-to-day life on this planet. With respect to the GOS, technology has driven dramatic improvements in both terrestrial and ocean-based observing systems: atmospheric soundings from more accurate rawinsondes with Global Positioning System-capability, shipboard sonde systems, and instrumented commercial aircraft through the Aircraft Meteorological Data Relay (AMDAR), all improve collection of upper-level wind measurements; automatic weather stations deployed in remote areas operate with improved reliability under extreme conditions; advanced digital Doppler radar systems providing integrated in-situ wind and precipitation measurements; technologically advanced ocean and ice buoys provide measurements of the marine and oceanic ice boundary layer environment; an array of free-drifting floats in every ocean provide information about the global heat balance; and a moored array of buoys in the tropical Pacific Ocean to provide insight on the El Nino - Southern Oscillation phenomenon (Tropical Ocean-Global Atmosphere (TOGA) Tropical Atmosphere-Ocean (TAO) array).

Advances in the space based component have been equally impressive. Instrumentation has developed well beyond the era of uncalibrated vidicon camera systems used on the early United States Television Infrared Observation Satellite (TIROS). They now include passive visible, infrared and microwave imaging systems for inferring atmosphere, cloud, land and sea surface properties; passive infrared and microwave atmospheric sounding systems for the determination of vertical temperature and moisture profile; and active microwave instruments for measuring rainfall, sea level altimetry and sea state.

The early success of the United States' meteorological space ventures to polar and geostationary orbit were followed by the development of similar systems by other nations resulting in a robust operational space based GOS. Today, operational polar orbiting systems are operated by China, the Russian Federation, and the United States and geostationary systems are operated by China, Europe, India, Japan, and the United States, with plans by Europe to enter the polar orbiting satellite arena and plans by the Republic of Korea and the Russian Federation to provide operational services for WMO Members from geostationary orbit.

All operational polar and geostationary systems provide multi-channel digital imagery, while the United States' polar system also provides microwave imaging and sounding data, and both its polar and geostationary systems provide infrared sounding data. Furthermore, today's space-based component of the GOS is composed of a robust operational component that is supplemented by a dynamic research component, with research satellites providing high resolution multi-spectral imagery and hyperspectral sounding data for use by WMO Members as well as enabling derivation of tropical rainfall, ocean surface winds, and altimetry.

## GOS EVOLUTION - THE WAY AHEAD

Growth of the GOS is expected to continue at an astounding rate! Major improvements are expected for the accuracy and timeliness from both in situ and remotely sensed data platforms. Furthermore, the volume of data associated with the newer GOS, especially those related to satellite and radar systems, is expected to increase exponentially over the next decade. A key aspect of realizing the benefits of all of this data for analysis and predictions of environmental conditions will be the development and implementation of sophisticated data assimilation systems. The data assimilation step is crucial to maximize the strengths of each observing system while minimizing their weaknesses in order to improve the analysis, initial conditions and subsequent forecasts for weather, water and climate, and especially for extreme events.

At the direction of the World Meteorological Congress, WMO's Commission on Basic Systems (CBS) studied the evolution of the GOS and issued WMO/TD No. 1267: *Implementation Plan for Evolution of Space and Surface-Based Sub-Systems of the GOS*. One main purpose of the plan was to help Members prepare for the massive changes in the GOS that were anticipated over the next two decades. Forty-seven recommendations in the plan provided the framework for the evolution of the GOS.

Twenty recommendations for the space-based sub-system addressed calibration, multi-spectral imaging (tens of channels) and hyper-spectral sounding (thousands of channels), ocean surface wind and altimetry, temporal coverage for low earth orbiting (LEO) satellites, atmospheric wind and aerosol profiles from active sensors, global measurements of precipitation using active radar and passive microwave sensors, and radio occultation sounders.

Twenty-seven recommendations for the ground-based sub-system addressed data coverage, distribution and coding, broader use of ground based and in situ observations, moving toward operational use of targeted observations, optimization of rawinsonde distribution and launches, development of the AMDAR Program and alternative AMDAR systems, atmospheric moisture measurements, improved observations in ocean areas, improved observations over tropical areas and new observing technologies.

The developers of the plan recognized its evolutionary nature and as a result for most of the recommendations provided comments concerning the recommendation, progress if the associated activity was already underway, actions that reflected what was to occur next, and schedules for the realization of the recommendation. On a regular basis CBS is reporting back to Members on the status of the implementation recommended in this plan.

One main purpose of the plan was to help Members prepare for the anticipated massive changes in the GOS. In that document, three issues are brought forward that must be addressed for successful implementation of an evolved GOS. They deal with continuity, utilization and cooperation:

- The future GOS should build upon existing sub-systems, both surface and space based, and capitalize on existing and new observing technologies not presently incorporated or fully exploited; each incremental addition to the GOS will be reflected in better data, products and services from the NMHS';
- The scope of the next decades' changes to the GOS will be so massive that new revolutionary approaches for science, data handling, data access, product development, training, and utilization will be required. There is an urgent need to study comprehensive strategies for anticipating and evaluating changes to the GOS;

The implementation of the new GOS should facilitate the strengthening of cooperation at national, regional, and global levels among Members. The evolution of the GOS in developing countries must address some of the issues that fall into three categories: a) infrastructure; b) training; and, c) equipment and consumables.

The evolution of the GOS will be greatly aided by The Observing System Research and Predictability Experiment (THORPEX), where new technologies and new adaptive observing strategies and data assimilation will be tested and guidelines for their utilization within the GOS for weather forecasts on a one- to fourteen-day timeframe will be developed (Figure B-2). Other studies will deal with the exploitation of the new data and information from the GOS being exploited for nowcasting and seasonal to interannual and longer term climate studies.

Studies such as those envisioned by

Figure B-2. The evolution of the GOS will be greatly aided by The Observing System Research and Predictability Experiment (THORPEX). New technologies and adaptive observing strategies and data assimilation will be tested and guidelines for their utilization within the GOS for weather forecasts on a one- to two-week timeframe will be developed.

THORPEX require a stable baseline observing system against which their results can be measured. In the development of the vision for the GOS by 2015, the space based sub-system was based on well defined plans by the operational and research space agencies. Thus for the space based sub-system we expect as a baseline an improved stable operational analysis and prediction systems complemented by a known dynamic research component focused on key observing issues and related data assimilation advances required to take full advantage of improved observations and associated observing strategies, especially those related to targeted observations.

For the surface based sub-system to become a viable baseline requires some components to either grow or become reinvigorated. Foremost among them are a complete and stable Regional Basic Climate Network (RBCN) embedded within a wholesome Regional Basic Synoptic Network (RBSN) where some components may be operated in a flexible manner, improvements in AMDAR and Troposphere Airborne Meteorological Data Reports (TAMDAR), and increased oceanic coverage to include upper air soundings, drifting buoys, and Argo floats; thus providing a stable baseline against which new observing technologies and strategies could be tested. Argo, drifting buoys and other oceanic observations are also critical elements of GOOS.

Other high priority GOOS observation systems and capabilities that contribute to GOS are: 1) tsunami warning capabilities in the Pacific and Atlantic Oceans, and the Caribbean sea as part of an International Tsunami Warning System (http://www.prh. noaa.gov /itic/); 2) Global Sea Level Observation System (http://www.pol.ac.uk/psmsl /programmes/gloss.info.html); and 3) Global Ocean Data Assimilation Experiment (www.uwgodae. org).

Thus, we can see that the 21st Century will be one filled with opportunity and challenge. The intersection of the technological advances referred to earlier with advances in communications capabilities provides an unprecedented opportunity to capitalize on the phenomenal growth in data and information that will become available during the first 25 years of this century.

Particularly relevant is the evolution of the WMO Information System (WIS) and how it will allow for the provision of data and information, and its use within a wide array of model-based prediction systems to Members on scales appropriate to their needs.

## DATA AND MODELS

Numerical Weather Prediction (NWP) relies on measurements of temperature (and/or pressure), winds and moisture. There is no single observing system that can provide all three parameters at the same place and the same time with the required accuracy. Also, there is no single observing system that provides a uniform (in space and time) distribution of these measurements. Both ground based and space based components of the GOS present a major challenge to derive data assimilation and modeling systems which account for the strengths of each observing system while avoiding their weaknesses.

For example, the data assimilation should be able to take into account the poor vertical but good horizontal resolution and spatial distribution of satellite data while also accounting for the good vertical but poor horizontal and temporal resolution of radiosonde data. Likewise, the system should also be able to account for the good temporal resolution but poor spatial distribution of aircraft data. It is through sophisticated assimilation systems and models that a coherent depiction of the earth-atmosphere from the measurements achieved by the GOS will hopefully be derived.

During the next decade, with advanced satellite systems, ground based radar, AMDAR and other in-situ systems there will be over a million times increase in the amount of data that is available. Most of that data will be focused on global NWP through complex data assimilation systems which are an inherent component of the entire prediction system and it is highly unlikely that any NMHS will want all of the data all of the time; but all NMHS' will want some of that data all of the time and portions of that data some of the time. While models appear to be entering an era of targeted observations, for NMHS' there can be no doubt that a targeted information era has begun.

Up to five years ago it was not possible to realistically address this issue; however, today the symbiotic relationship that is developing between technology and communications is making it a reality. Thus data that flows through the WIS will be made up of a stable operational component complemented by a dynamic segment that depends on user needs, model capabilities and advances in data assimilation. Defining how those two components coexist will require development work that addresses societal needs, NMHS capability, WIS components and the symbiotic relationship between technology and communications.

As the requirements on Members for user services is growing, it is not unreasonable to expect Member needs from the GOS to expand. In the past, global NWP requirements for data were based on communications and computer technology that were applicable to the mid to late 20th Century. Today, modern Global Data Processing Centers (GDPCs) are using exceptionally powerful computers with advanced data assimilation models which couple asynoptic data into models with advanced physics.

Both Observing System Experiments (OSEs) and Observing System Simulation Experiments (OSSEs) have clearly shown that continuous assimilation of high resolution data into those models results in improved global forecasts. During the past decade this has changed so that to provide the best forecasts today's modern GDPCs now require all data from upper air observations, not just significant level data, as well as hourly surface data and data from special networks. This need lies beyond the current scope of Resolution 40, but clearly, any Member that is truly interested in accurate global forecasts must respond to that need. An innovative outlook means trust across borders, nation to nation, level of government to level of government, and government to citizen. An innovative outlook means that the user becomes integrated as a part of the system at all levels. To avail ourselves of that opportunity will require Members to work together in global science and operational partnerships.

Distribution of increased amounts and types of data for WMO and related programs is under development in the Future WMO Information System (FWIS; http://www.wmo.ch/web/www/FWIS-Web/homefwis.html). FWIS will build on the current GTS that communicates data among processing centers.

## STAFFING AND TRAINING

Some fear that the role of the human will decrease with this revolution in technology. Nothing could be further from the truth. While some activities will be replaced through better uses of technology, the increase in data volume, products and applications areas will place the human at the very heart of maximizing the use of this impressive system. Our ability to monitor and forecast on a global scale will place the human at the very center of how that information is used on a daily basis in a tremendous number of applications areas.

By anticipating the weather of the next week will allow for applications to focus on mitigation of natural disasters through concentrating on regions prone for flooding and then managing the information and data flow into the NMHS that will allow for those phenomena to be addressed in an efficient and timely manner. Thus, training an increasingly diverse user community in how to utilize the system and to access the correct data for a specific application will be of paramount importance.

Furthermore, training in advanced applications of satellite data and its use in nowcasts and numerical prediction systems will take on increasing importance. Satellite data will provide information for a variety of real-time applications that range from nowcasting severe weather and floods to detection and monitoring of: areas of snow melt, wet ground, fires, aerosols, surface temperature for heat stress, and forecast model output fields. With the massive increase in information and data that will become available over the next decade it is necessary for WMO to embrace even more training opportunities, especially as it relates to developing and implementing more sophisticated data assimilation system designs with the future GOS in mind.

## STRONG TIES TO GEOSS

The phenomenal growth and increase in capability that are expected to occur within the GOS places it on a natural intersection with GEOSS. Indeed, there is a clear juxtaposition between GOS and GEOSS. In June 2004, the fifty-sixth session of the WMO Executive Council formally declared that several WMO systems including GOS and WIS should be considered as core components for GEOSS. Furthermore, in the long view the GOS, in some ways, cross-cuts each of the GEOSS nine societal benefit areas, some quite substantially:

- Improving weather information, forecasting and warning
- Reducing loss of life and property from natural and human induced disasters
- Improving water resource management through better understanding of the water cycle
- Understanding, assessing, predicting, mitigating and adapting to climate variability and change
- Improving the management and protection of terrestrial, coastal and marine ecosystems
- Understanding environmental factors affecting human health and well being
- Improving management of energy resources
- Supporting sustainable agriculture and combating desertification
- Understanding, monitoring and conserving biodiversity

WMO is a strong contributor to GEOSS, and is home to the Secretariat of the intergovernmental Group on Earth Observations (GEO) at its headquarters in Geneva[2]. WMO is also a strong contributor to GOOS. GOOS is composed of global ocean and coastal ocean components, and has several submodules: the Global Climate Observing System (GCOS), Living Marine Resources Panel, Health of the Oceans, and the Global Terrestrial Observing System. In fact the GCOS program, of which the WMO is a prime sponsor, has been recognized as the formal climate component of the GEOSS; the GCOS Implementation Plan which can be found at http://www.wmo.int/web/gcos/gcoshome.html is part of the overall GEOSS implementation effort.

The space and ground-based components of the WWW are among the core contributors to GEOSS (Figure B-3). Observing and accurately predicting the Earth's environment is critical for the health, safety and prosperity of all nations. As responsibilities of WMO

2 WMO is the physical host of the GEO Secretariat, but the Secretariat operates at the direction of the Group on Earth Observations Plenary.

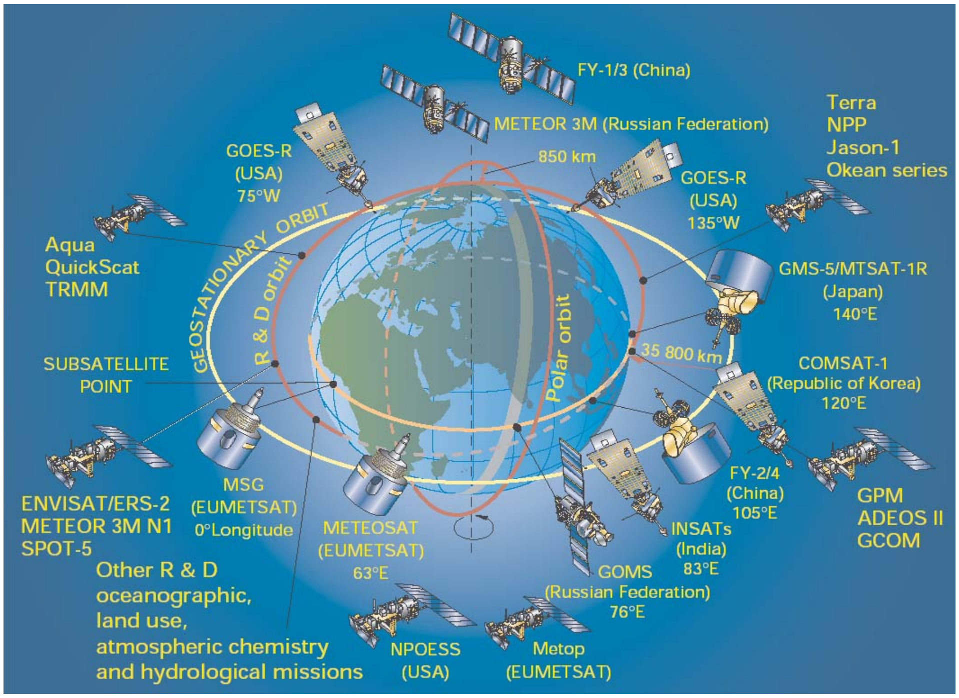


Figure B-3. The space-based component of the GOS.

Members increase to take on broader roles in monitoring and forecasting for the environment, many of the sub-systems that contribute to GEOSS that are not part of the WWW will become important for WMO Members.

Too often we become enthralled with placing an economic value on the need to justify monitoring climate, weather and the Earth's environment as well as our ability to forecast them. As is clearly recognized by the GEOSS 10 Year Implementation Plan: "*Understanding the Earth system - its weather, climate, oceans, land, geography, natural resources, and natural and human-induced hazards - is crucial to enhancing human health, safety and welfare, alleviating human suffering including poverty, protecting the global environment, and achieving sustainable development*."

The reason we want to monitor the "pulse of our planet" is not solely for economic benefit but for human health and well being while learning how to sustain humankind's future on our evolving planet Earth.

## THE GOS FUTURE AND NHMS'

There is no question that we are improving in our ability to utilize data from the GOS. The reason clearly lies in more and better observations and our ability to utilize them. Today we have improved high resolution models with better physics that are linked to the improved observations with powerful data assimilation systems. As the GOS evolves continued progress in science, models and data assimilation coupled with awareness of importance of transitions will help guide us toward full utilization. As we move forward, there are some critical questions that will accompany the implementation of the evolving GOS:

- The broad implications of targeted observations need to be addressed, with guidance on targeting needing to be developed only after careful scientific consideration;
- How adaptive observing is implemented within the GOS needs full consideration as observations not deemed necessary at a particular instant in time in one part of the world may provide valuable information elsewhere;
- How Members can best benefit from the tremendous amounts of data that will become available;
- How we fully train Members to utilize data from the GOS so that opportunities are not lost;
- While not all Members will have the ability to cope with the full data sets, all Members will have a responsibility to contribute fully to the evolving GOS, this will likely require refinements to data exchange policy.

Applications areas are expanding dramatically with an unparalleled opportunity for growth. For almost any given applications area opportunities to exploit multiple data sets from a variety of sensors, all with different characteristics, will abound. Data volumes will be tremendous in comparison with today's operational systems - at least six orders of magnitude.

We should expect great improvements to the GOS; including very high spatial and temporal resolution with both space-based and ground-based active and passive sensors. In concert with these new capabilities we must prepare for vast growth in data volume and content which will be available from systems in just the first few decades of this new century. On the horizon lies the promise of improved data for the various services Members provide. Better science will occur by realizing the opportunities afforded by the future GOS through new approaches, international partnerships and science teams.

Planning for tomorrow's GOS must take into account all observing assets, capitalizing on their strengths as a key component of a comprehensive and sustained GEOSS. As we take advantage of the future's promise, marked changes will occur in the ways we approach data handling, science, product development, training and utilization. To prepare for the daunting task of monitoring and understanding the Earth system from these new data, and ensuring their full utilization, we must work together in global science and operational partnerships.

We move forward by building on the successes of today and aggressively planning and developing appropriate mechanisms focused on exploitation as a global community in partnership: the user, national and international science groups, operational agencies, research satellite agencies, and WMO. To do this is a challenge, but it is a challenge that must be met.

We strive for full exploitation, but whose responsibility is it to ensure the future GOS is utilized to maximize benefit in a given applications area: the user, national and international science groups, the operational agencies, the research agencies, WMO? In fact, the responsibility rests with all communities. In this regard, GOS as part of GEOSS will provide a wider spectrum of users and further increase the value of its observations.